EEDP-06-11
January 1990

Environmental Effects of Dredging Technical Notes

PRELIMINARY GUIDELINES AND CONCEPTUAL FRAMEWORK FOR COMPREHENSIVE ANALYSIS OF MIGRATION PATHWAYS (CAMP) OF CONTAMINATED DREDGED MATERIAL

PURPOSE: The purpose of this note is to present the conceptual groundwork for the Comprehensive Analysis of Migration Pathways (CAMP). The conceptualization process for CAMP is discussed and available techniques for implementing CAMP are examined. Disposal of contaminated dredged material in a confined disposal facility is used to benchmark conceptual development. Case studies that illustrate analysis of selected migration pathways are also described.

BACKGROUND: The US Army Corps of Engineers performs a variety of mission-related activities that require analysis of the movement of chemicals in soil, water, and air. One of these activities involves dredging and disposal of contaminated sediments. The need to evaluate dredged material disposal alternatives has prompted the development and continued improvement of procedures and supporting laboratory tests for evaluating disposal alternatives (Francingues et al. 1985; Lee et al. 1985; Cullinane et al. 1986). These effects-based procedures do not always fully resolve the relative merit of disposal alternatives when contaminated sediments are involved. CAMP is being developed as an internally consistent set of procedures for comparing the containment efficiency of disposal alternatives and as such to provide supporting documentation for evaluating alternatives. CAMP is intended to interact with, but is not a substitute for, the existing effects-based procedures.

ADDITIONAL INFORMATION OR QUESTIONS: Contact the author, Mr. Tommy E. Myers, (601) 634-3939, or the manager of the Environmental Effects of Dredging Programs, Dr. Robert M. Engler, (601) 634-3624.

Introduction

Many environmental regulatory agencies are beginning to emphasize assessment of total mass losses of contaminants through all pathways in their evaluation of dredged material disposal alternatives. Existing procedures such as the Corps of Engineers (CE) management strategy (Francingues et al. 1985), the decisionmaking framework (Peddicord et al. 1986), and the dredged material

alternative selection strategy (DMASS) (Cullinane et al. 1986) incorporate independent analysis of contaminant migration pathways to estimate effects. Estimated effects are compared to criteria established by regulatory authorities to arrive at decisions regarding the suitability of an alternative, including the need for restrictions. When acceptable combinations of restrictions cannot be identified, however, no guidelines exist for objectively evaluating trade-offs between alternatives, including the no-action alternative. Development of a comparative assessment methodology that interacts with effects-based assessments to provide additional guidance for evaluating disposal alternatives is therefore needed.

Basic CAMP Concept

CAMP is structured around the time-honored engineering concept of a materials balance. The rate of contaminant mass into a control volume minus the rate of contaminant mass out of the same control volume is the rate of contaminant mass containment for the control volume. Containment efficiency (CEF) for an alternative is defined as follows:

$$CEF = \sum_{i=1}^{n} \sum_{j=1}^{m} \frac{(\text{Rate of Mass In})_{i,j} - (\text{Rate of Mass Out})_{i,j}}{(\text{Rate of Mass In})_{i,j}}$$

where i is the contaminant index, j is the pathway index, n is the number of contaminants included in the analysis, and m is the number of pathways included in the analysis. Estimated materials balances provided by CAMP can be used to compare various disposal alternatives. If rate of contaminant reentry into the environment can be determined for the no-action alternative, then dredging and disposal alternatives can be compared to the no-action alternative on the basis of rates of contaminant flux to the environment. This will involve combining estimates of the rate of contaminant mass loss for various disposal alternatives with estimates of the rate of contaminant mass loss for dredging operations to arrive at an overall rate of contaminant loss for a proposed project.

Thus, the basic concept of CAMP is very simple. Pathways are routes by which contaminants enter and/or exit a control volume. The rates at which contaminant masses are transported along pathways determine containment efficiency. Implementation of this simple concept presents three types of challenges: definition of the spatial scale for a control volume, estimation of contaminant migration rates along pathways, and definition of the temporal scale for conducting an analyis.

The spatial scale over which to conduct a materials balance is relatively straightforward for confined disposal facilities (CDFs) and other disposal alternatives involving confinement. The spatial scale for a CDF is the confining dikes, the interface between foundation soils and dredged material, and the surface of the CDF. Similarly, the spatial scale for an alternative that involves treatment is the treatment process unit. The appropriate spatial scale for the no-action alternative is site specific and sometimes difficult to determine. It might be the boundaries of a harbor or of the Federal project.

Estimation of contaminant mass flux along pathways for which predictive methods are unavailable or unverified is likely to introduce a high degree of uncertainity into CAMP. For some pathways, established procedures can be adapted to estimation of contaminant mass flux. For example, the modified elutriate test (Palermo 1988) can be used to estimate contaminant mass flux associated with discharge of an effluent during hydraulic disposal. For pathways such as volatile emissions, theoretical models are the only tools available for estimating contaminant mass flux (Thibodeaux 1989). For other pathways such as those involving uptake by biota that move into and out of a control volume, predictive methods may not be available.

The temporal scale for conducting a comprehensive materials balance is not as easily defined as the spatial scale. First, the relative importance of various pathways varies in time. For example, discharge of water during filling operations is an important pathway during filling of a CDF. After the CDF is filled, discharge associated with filling ceases. Thus, the time dependency of contaminant fluxes must be incorporated into CAMP. Further, the overall time scale must be considered. Most disposal alternatives for contaminated sediments and other residues are permanent or at least permanently maintained. The appropriate magnitude of the time scale for CAMP has not yet been determined.

CAMP Information Needs/Objectives

The following list of questions are typical ones that need to be answered for the development of CAMP as a useful tool. The list also indicates the types of questions that an application of CAMP should answer. The list has been specifically prepared for CDFs.

1. What is the relative significance of each pathway during each phase of the existence of a CDF (filling, between filling operations, partially vegetated, and filled)?

2. How does pathway significance relate to site management and/or application of control technologies?

3. What is known (and not known) about mechanisms and rates for each pathway? Are computational procedures available? What research is required to develop needed computational procedures?

4. What are the relationships among pathways?

5. How do changing physicochemical conditions and biological processes in the CDF affect contaminant mobility?

6. What is the appropriate temporal scale for evaluating long-term release of contaminants from CDFs?

CDF Pathways

Brannon et al. (in preparation) identified key contaminant mobility processes and pathways and, where possible, methods for estimating contaminant mass exit rates for CDFs. Available information of contaminant migration, cycling, and mobilization pathways is summarized in Table 1. Pathways involving movement of large masses of water, such as CDF effluent and discharge through permeable dikes, have the greatest potential for moving significant quantities of contaminants out of CDFs. Pathways such as volatilization may also result in movement of substantial amounts of volatile organic chemicals at certain stages in the filling of a CDF. The relative importance of contaminant cycling and mobilization in a CDF to net mass balance has not been determined.

Table 1 indicates the importance of basing CAMP on an understanding of the mass balances that are established as chemicals are transported along migration pathways. Apparently, calculation of materials balances for CDFs will involve application of multimedia models for many pathways. Advances in the use and

Table 1

Status of Available Information on Contaminant Migration, Cycling, and Mobilization Pathways*

Pathway	Status
CDF Effluent	Empirical methods exist for assessing CDF effluent
Water Transport Through Permeable Dikes	Methods for making crude estimates that do not account for many of the variables affecting this pathway have been used
Leaching	Methods are under development
Volatilization	Unverified predictive equations have been formulated
Surface Runoff	Empirical methods have been developed
Degradation of Organic Contaminants	No information is available for CDFs, but much work has been conducted in soils and sediments
Microbial Transformations of Metals	Importance in a CDF environment has not been shown
Mobilization by Microorganisms	Almost no information is available
Plant Uptake	Predictive models are being developed for metals under certain conditions; limited information is available in the literature for organic contaminants
Animal Uptake	Limited information is available for CDFs; no predictive models are available for CDFs

* From Brannon et al. (in preparation)

acceptance of multimedia environmental models were reviewed by Bird (1988), and the applicability of multimedia models to CDFs was reviewed recently by Martin and McCutcheon (in preparation). Public domain models are available that may have applicability to CDFs as follows:

1. MINTEQ (Felmy, Girvin, and Jenne 1984) calculates aqueous equilibrium speciation of metals. This model may be useful for estimating metal mobility under the various physicochemical conditions that occur in CDFs.

2. HELP (Schroeder et al. 1984) calculates seepage from landfills and provides information needed for developing liner specifications. This model, as discussed in a later section, has been used in conjunction with data from sediment leaching tests to estimate contaminant migration by leachate seepage from CDFs.

3. TOXI4 (Ambrose et al. 1988) simulates chemical transport in surface water and includes sediment-water column exchange. TOXI4 has been modified, as discussed in a later section, to model exposure concentrations and releases from CDFs (Martin, Ambrose, and McCutcheon 1988).

4. PRZM (Carsel, Smith, and Mulkey 1984) is an agricultural model that consists of hydrology and chemical transport components that simulate runoff, erosion, plant uptake, leaching, decay, foliar washoff, and volatilization of pesticides. PRZM may be useful for estimating percolation and runoff from exposed surfaces in CDFs.

5. FGETS (Barber and Suarez 1989), WASTOX-PART II (Connolly and Thomann 1984), and TEEAM (Dean et al. 1988) are organic chemical biouptake and bioaccumulation models that might be useful in assessing biological processes involved in internal cycling of contaminants that ultimately exit CDFs.

In addition, theoretical volatile chemical emission models (Thibodeaux 1989) and numerous groundwater models (Janandel, Doughty, and Tsang 1984) are available for application to CDFs. Although no single presently available model considers all of the myriad of processes and pathways in a CDF, some combination of the models available may be sufficient to provide first-order evaluations.

Much work is needed before models can be adopted for routine application to CDFs since model application to CDFs is largely unvalidated. Additional model development as well as supporting field and laboratory data are required to develop fully predictive tools. Additional discussions of available computational procedures and research needs for comprehensive analysis of migration pathways in CDFs can be found in Brannon et al. (in preparation) and Martin and McCutcheon (in preparation).

Example Case Studies

Estimates of contaminant losses from CDFs are being made in spite of the fact that some of the laboratory tests and computer models that are used have not been field proven (Myers, Miller, and Snitz 1988). Some case studies are briefly described below. The reader should consult the references for more detailed descriptions.

Chicago District activities

The Chicago District often uses mechanical dredging and disposal in CDFs. Region V of the US Environmental Protection Agency requested estimates of dissolved contaminant losses through dikes from existing and proposed CDFs in the

Chicago District. The District developed in-house models for this purpose (US Army Engineer District, Chicago 1986). The models simulate formation of dredged material deltas during disposal and the impacts of delta formation on the release of interstitial water and dike seepage. Equilibrium partitioning concepts are used to estimate interstitial water concentrations. Interstitial water that is released from the sediment is mixed with overlying water and transported through the dikes without attenuation.

Everett Harbor, Washington

The US Navy proposed to establish a homeport for a carrier battle group at Everett, Washington, and requested the Seattle District to provide technical assistance in developing a dredging and disposal plan for sediment that would have to be relocated. The Seattle District in turn requested technical assistance from the US Army Engineer Waterways Experiment Station (Palermo et al. 1989). One interesting aspect of the evaluation of dredging and disposal alternatives was estimation of total contaminant mass loss for both dredging and disposal. A containment performance goal of 95 percent of total contaminant mass in the in-place sediments was used to judge the relative merit of dredging and disposal options. The containment efficiency for confined aquatic disposal (CAD) using clamshell dredging with surface release from bottom dump barges met the performance criterion and was better than that for hydraulic dredging and disposal in CDFs (Palermo et al. 1989).

New Bedford Harbor, Massachusetts

New Bedford Harbor is a Superfund site in southern Massachusetts. Proposed remedial actions involve dredging and disposal of contaminated sediments in the Acushnet River estuary. Averett et al. (1988) calculated polychlorinated biphenyl (PCB) and heavy metal releases for various CDF disposal alternatives using hydraulic dredging. PCB mass releases for selected CDF alternatives are shown in Figure 1. Alternative A1 is an unlined CDF with earthfill (low hydraulic conductivity) dikes. The effluent associated with filling operations is not treated in Alternative A1. Alternative A2 includes treatment of the effluent for suspended solids removal. Alternative A3 includes treatment of the effluent for suspended solids removal and dissolved PCB removal using activated carbon. Alternative D is a lined CDF with effluent treatment for suspended solids and dissolved PCB removal.

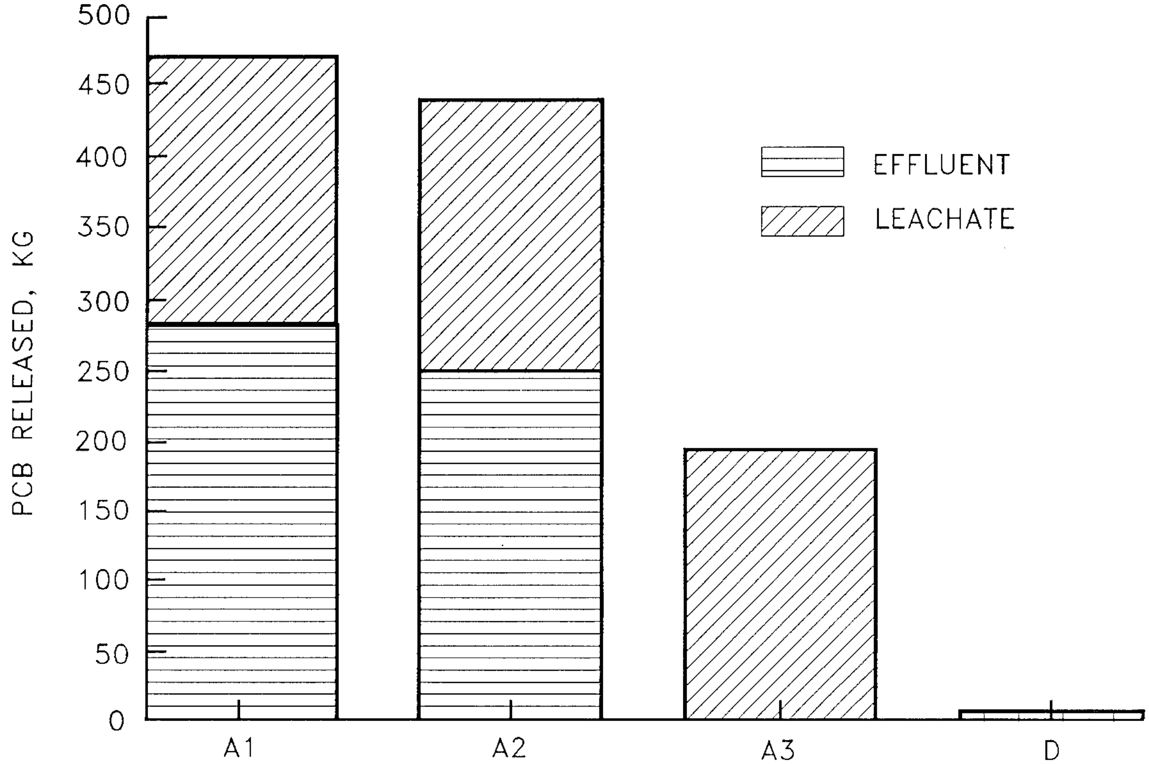

Figure 1. PCB release estimates for selected New Bedford Harbor CDF alternatives (from Averett et al. 1988)

The estimation techniques used by Averett et al. (1988) are too involved to describe in detail in this technical note. Noteworthy aspects of the calculations are summarized as follows:

1. Analysis of the CDF contaminant migration pathways included water discharged during hydraulic filling and leachate seepage. Runoff and volatilization were not pathways of concern because the CDF alternatives included capping.

2. PCB release during filling was calculated directly from suspended sediment and dissolved contaminant concentrations observed in the modified elutriate test and dredge flow rate.

3. Long-term (30 years) PCB migration via leachate seepage was analyzed by combining leachate quality data obtained in laboratory leach tests with percolation estimates from a version of the HELP model set up specifically for dredged material.

4. Short-term PCB migration via leachate seepage was estimated by analyzing consolidation and release of pore water using the PCDDF model (Cargill 1985).

TOXI4 application

Martin, Ambrose, and McCutcheon (1988) modified selected algorithms in the TOXI4 model (Ambrose et al. 1988) to model PCB transport through permeable dikes. Application of the model to a proposed in-lake CDF at Indiana Harbor, Indiana, showed that contaminant transport through permeable dikes at in-water CDFs is affected by the type of filling (hydraulic or mechanical), sorption properties of the dike material, and hydraulic pumping. Hydraulic pumping is the movement of lake water into and out of the dikes due to fluctuation in lake levels that occurs between filling operations. Hydraulic pumping was modeled as dispersion.

The estimates provided by TOXI4 (Table 2) for mechanical filling of the Indiana Harbor CDF were close to previous estimates developed by the Environmental Laboratory (1987) when significant partitioning of PCB to dike materials was simulated and flux due to hydraulic pumping (dispersion) was not included in the estimate. PCB flux due to hydraulic pumping exceeded advection losses for all simulations, including those conducted for hydraulic filling. TOXI4 estimates of combined advection and hydraulic pumping for hydraulic filling were, however, lower than those developed by the Environmental Laboratory (1987) for hydraulic filling.

Table 2

TOXI4 Estimated Releases of PCBs (kg) from the Proposed Indiana Harbor CDF (from Martin, Ambrose, and McCutcheon 1988).

		Loss Through Permeable Dike			
		Low Partitioning		High Partitioning	
Dredging	EL*	A*	D*	A	D
Hydraulic	6.3	0.37	1.9	0.03	0.5
Mechanical	0.0003	--	--	0.004	0.2

*Note: EL: loss estimates provided in Environmental Laboratory (1987).
A: advective loss due to flow through the dike.
D: dispersive loss due to hydraulic pumping.

Accesion For
NTIS CRA&I ☑
DTIC TAB ☐
Unannounced ☐
Justification
By Per Form 50
Distribution /
Availability Codes
Dist | Avail and / or Special
A-1

CAMP Research and Development Needs for CDFs

Established procedures are available for estimating contaminant mass flow over weirs during hydraulic filling, the major contaminant migration pathway

during hydraulic filling of CDFs with low permeability dikes. Existing procedures for other pathways are not fully developed and are probably suitable for reconnaissance-level estimation only.

Contaminant migration pathways requiring additional work include transport through dikes, leachate seepage, volatilization, and surface runoff. Research is also needed on the release of contaminants from mechanically dredged material during disposal, biodegradation of toxic organics, chemical and biological transformations of contaminants, and plant and animal uptake in CDFs. Pathways involving movement of water have the greatest potential for moving significant quantities of contaminants out of CDFs and, therefore, should have first priority.

References

Ambrose, R. B., Jr., Wool, T. A., Connolly, J. P., and Schanz, R. B. 1988. "WASP4, A Hydrodynamic and Water Quality Model--Model Theory, User's Manual, and Programmer's Guide," EPA/600/3-87/039, Environmental Research Laboratory, US Environmental Protection Agency, Athens, GA.

Averett, D. E., Palermo, M. R., Otis, M. J., and Rubinoff, P. B. 1988. "New Bedford Harbor Superfund Project, Acushnet River Estuary Engineering Feasibility Study of Dredging and Dredged Material Disposal Alternatives; Report 11, Evaluation of Conceptual Dredging and Disposal Alternatives," Technical Report EL-88-15, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Barber, N. C., and Suarez, L. A. 1989. "Food and Gill Exchange of Toxic Substances (FGETS2)," Draft Report, Environmental Research Laboratory, US Environmental Protection Agency, Athens, GA.

Bird, S. L. 1988. "Contaminant Modeling," Environmental Effects of Dredging Technical Note EEDP-01-11, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Brannon, J. M., Pennington, J. C., Gunnison, D., and Myers, T. E. "Comprehensive Analysis of Migration Pathways (CAMP): Migration Pathways Controlling Internal Cycling and Net Mass Transport of Contaminants at Confined Dredged Material Disposal Facilities," Miscellaneous Paper in preparation, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Cargill, K. W. 1985. "Mathematical Model of the Consolidation/Desiccation Processes in Dredged Material," Technical Report D-85-4, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Carsel, R. F., Smith, C. N., and Mulkey, L. A. 1984. "User's Manual for the Pesticide Root Zone Model (PRZM)," EPA/600/3-84-109, Environmental Research Laboratory, US Environmental Protection Agency, Athens, GA.

Connolly, J. P., and Thomann, R. V. 1984. "WASTOX, A Framework For Modeling the Fate of Toxic Materials in Aquatic Environments, Part 2: Food Chain," Cooperative Agreement R807853, Large Lakes Research Station, US Environmental Protection Agency, Grosse Ile, MI.

Cullinane, M. J., Averett, D. E., Shafer, R. A., Male, J. W., Truitt, C. L., and Bradbury, M. R. 1986. "Guidelines for Selecting Control and Treatment Options for Contaminated Dredged Material Requiring Restrictions," Prepared for Puget Sound Dredged Disposal Analysis, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Dean, J. D., Voos, K. A., Schanz, R. W., and Popenuck, B. P. 1988. "Terrestrial Ecosystem Exposure Assessment Model (TEEAM): Final Report and Code Documentation," Contract No. 68-03-6305, prepared for the Environmental Research Laboratory, US Environmental Protection Agency, Athens, GA.

Environmental Laboratory. 1987. "Disposal Alternatives for PCB-Contaminated Sediments from Indiana Harbor, Indiana: Volume II," Miscellaneous Paper EL-87-9, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Felmy, A. R., Girvin, D. C., and Jenne, E. A. 1984. "MINTEQ--A Computer Program for Calculating Aqueous Geochemical Equilibria," EPA/600/3-84/032, Environmental Research Laboratory, US Environmental Protection Agency, Athens, GA.

Francingues, N. R., Jr., Palermo, M. R., Lee, C. R., and Peddicord, R. K. 1985. "Management Strategy for Disposal of Dredged Material: Contaminant Testing and Controls," Miscellaneous Paper D-85-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Janandel, I., Doughty, C., and Tsang, C. F. 1984. *Groundwater Transport: Handbook of Mathematical Models*, Water Resources Monograph Series 10, American Geophysical Union, Washington, DC.

Lee, C. R., Peddicord, R. K., Palermo, M. R., Francingues, N. R., Jr. 1985. "Decisionmaking Framework for Management of Dredged Material: Application to Commencement Bay, Washington," Miscellaneous Paper, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Martin, J. L., Ambrose, R. B., and McCutcheon, S. C. 1988. "Assessment Protocols for Confined Disposal Facilities: Time Variable TOXI4 Based CDF Model," Draft Report, Environmental Research Laboratory, US Environmental Protection Agency, Athens, GA.

Martin, J. L., and McCutcheon, S. C. "Overview of Processes Affecting Contaminant Release from Confined Disposal Facilities," Miscellaneous Paper in preparation, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Myers, T. E., Miller, J. A., and Snitz, F. L. 1988. "Recent Developments in Estimating Polychlorinated Biphenyl (PCB) Losses from Confined Disposal Facilities," Water Quality '88 Seminar Proceedings, Committee on Water Quality, US Army Corps of Engineers, Washington, DC.

Palermo, M. R. 1988. "Field Evaluations of the Quality of Effluent from Confined Dredged Material Disposal Areas," Technical Report D-88-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Palermo, M. R., et al. 1989. "Evaluation of Dredged Material Disposal Alternatives for US Navy Homeport at Everett, Washington," Technical Report EL-89-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Peddicord, R. K., Lee, C. R., Palermo, M. R., and Francingues, N. R., Jr. 1986. "General Decision-Making Framework for Management of Dredged Material: Example Application to Commencement Bay, Washington," Miscellaneous Paper, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Schroeder, P. R., Morgan, J. M., Walski, T. M., and Gibson, A. C. 1984. "The Hydrologic Evaluation of Landfill Performance (HELP) Model," EPA/530-SW-84-009, US Environmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati, OH, and Office of Solid Waste and Emergency Response, Washington, DC.

Thibodeaux, L. J. 1989. "Theoretical Models for Evaluation of Volatile Emissions to Air during Dredged Material Disposal with Applications to New Bedford Harbor, Massachusetts," Miscellaneous Paper EL-89-3, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

US Army Engineer District, Chicago. 1986. "Draft Environmental Impact Statement: Indiana Harbor Confined Disposal Facility and Maintenance Dredgings, Lake County, Indiana," Chicago, IL.